

STRUCTURAL MATERIALS: TIMBER

Lecture by Peter Flynn

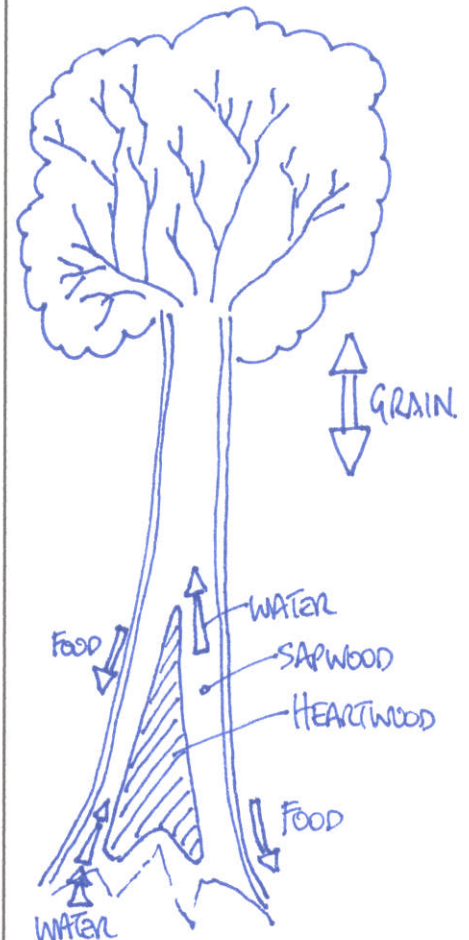
1. **INTRODUCTION:** Unlike steel and concrete, timber is a natural material and is not manufactured with consistent structural properties. It does not behave equally in all directions. Strength parallel to the grain is vastly different to strength and stiffness normal to the grain. Before we look at timber properties, it is important to look at the natural characteristics of timber.
2. **STRUCTURE OF WOOD:** Wood is composed of cells each with different functions. Some store and convey food and liquids from leaves and roots. Some provide strength and stability allowing the tree to support a canopy of leaves and to withstand gales. The conducting (food + liquid) and supporting cell tissue is vertically arranged and can be seen from the **grain** direction of the timber.

Food storage and conduction across the tree is through narrow ribbons of weak cells known as **rays** which run across the grain.

Softwoods have tracheas or vertical elements. Sap passes in the cavities between these tracheas. The spaces between the tracheas known as pits affects the timber permeability, which affects the degree of preservative that can be injected into the timber.

Hardwoods have vertical fibres rather than tracheids with thick walls and are very strong. Vertical pores exist between these fibres. These pores separate a hardwood from a softwood.

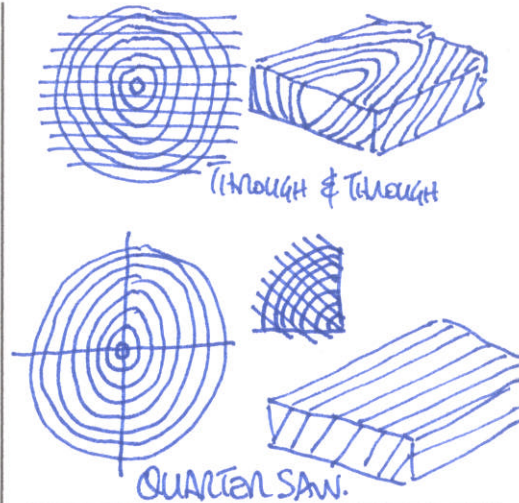
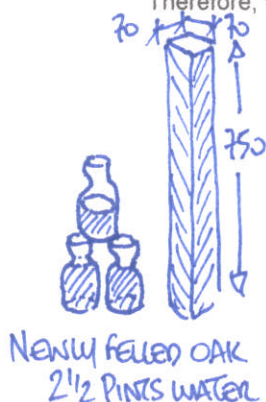
3. **WHAT IS WOOD?:** It is simply cellulose (sugar) bound with lignin (glue) plus lots of other compounds (such as hemicellulose, starch, calcium, salt, silica...)
4. **GROWTH RINGS:** Trees grow by producing a layer of external wood every year (normally). Each year a ring of wood is added to the tree. Each ring has a lighter, less dense section (from spring) and a darker, more dense section (autumn + summer).
5. **HEARTWOOD:** Many trees have a dark coloured area in the centre called heartwood. It provides the mechanical support for the tree and it becomes impermeable with age. The larger the diameter of the tree, the bigger the heartwood core. The heartwood of oak, for example, is so impermeable, it is the main reason why it is used in oak casks/barrels. Also, heartwood is very resistant to fungal or insect attack.



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6. **SAPWOOD:** exists outside the heartwood and conducts water from the roots to the leaves. Many softwoods (i.e. European Redwood) will nearly always contain a significant amount of sapwood as the trees are small in diameter.
7. **SAWING:** Through and through can produce an economical board which is susceptible to bowing and warping as the timber dries. Quarter sawing gives a board with growth rings at an angle of not less than 45° . This gives a stable wood that dries at an even rate. Expensive as the log must be turned and held during cutting.
8. **MOISTURE CONTENT:** expressed as a percentage of oven dry weight of wood. Green (newly fallen) could have a moisture content in excess of 100%! For example, a 2 kg lump of wood when dried could weigh 0.9 kg. This saturated wood will dry but will not shrink until it reaches a moisture content less than 28%. Below this figure, it will start to shrink. Air dried wood will have a moisture content of about 18% and internal wood should dried and worked at about 12%. Below 20%, you shouldn't get any fungal growth or decay.
9. **DENSITY:** Hardwoods vary from about 1230 kg/m^3 (Lignum Vitae and African Blackwood) to 190 kg/m^3 for Balsa (at 12% moisture content). Softwoods vary from 720 kg/m^3 (Pitch Pine) to 370 kg/m^3 (Western Red Cedar).
10. **STRENGTH:** Strong along its grain but weak across it. Weak in shear parallel to the grain. Weakened by knots, wanes, fissures, worm holes, defects or splits. So how do we know what stress to work to? Wood is **stress graded** visually and mechanically so when you design in wood you must specify what structural grade you are assuming. BS5268 Part 2 used to define nine classes from the weakest SC1 to the strongest SC9 with SC3 being a common class. The strength classes have been revised in the latest version of BS5268 Part2:1996 but you will still hear engineers referring to SC3 timber.
11. **FIRE:** Although combustible, the behaviour of timber is 'predictable'. It burns at a predictable speed known as the charring rate. The black charred part of timber has a thermal insulation that keeps the temperature of the wood a few millimetres below the burning surface at a normal temperature. Therefore, the unburned timber retains its strength.



Timber Density	Density kg/m^3
Lignum Vitae	1230
African Blackwood	1200
Ebony	1180
Green Heart	1030
Purple Heart	850
Hickory	820
Jar rah	800
Beech	720
Oak	720
Ash	720
Pitch Pine	710
Yew	660
Iroko	650
Teak	650
European Larch	590
Elm	570
Mahogany	550
Douglas Fir	520
Scots Pine	510
Joelton	470
Spruce	440
Obese	390
Western Red Cedar	370
Balsa	190

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12. **SMALL SCALE TENSILE AND COMPRESSION STRESSES**: theoretical stresses on small samples are dangerous. In tests, woods such as the Spruce or Douglas Fir fail at a tensile stress well in excess of 100N/mm^2 . The same woods as larger elements fail in compression at 40 to 50N/mm^2 .
13. **BENDING TESTS ON SMALL SAMPLES**: Very applicable to timber as its use structurally is for beams/joist. The **modulus of rupture** test gives us the stress on the tensile face that leads to failure. This stress can be as high as $75\text{ to }90\text{N/mm}^2$ for the spruce or fir.
14. **REAL LIFE**: Large pieces of timber have knots at points of high stress. The grain is distorted or doesn't quite line up. The rate of loading affects strength. If a load remains on the member for a long time, the member is weakened. Moisture Content affects strength. Oven-Dried wood is up to 3 times stronger than wood at its fibre saturation point. As temperature increases by $+1^\circ\text{C}$ timber can experience a 1% strength increase. A piece of wood can fail at 50% of the load it can carry initially some 100 years later (i.e. a bookcase).
15. **DESIGN STRESSES**: Work to a statistical set of 100 wood stresses and identify the stress that 99 out of the 100 test pieces can take. Then divide this stress by a **safety factor** (normally 2.25). In the design codes factors are applied to take account of time/age of loading, depth factors, width factors, load sharing factors, stress concentrations. This will give a **grade stress** or a permissible stress for design. Typical grade stresses and data for an **SC3/C16** timber are:
- Bending Parallel to Grain = 5.3 N/mm^2
 - Tension Parallel to Grain = 3.2 N/mm^2
 - Compression Parallel to Grain = 6.8 N/mm^2
 - Compression Normal to Grain = 2.2 N/mm^2
 - Shear Parallel to Grain = 0.67 N/mm^2
 - Modulus of Elasticity (Mean) = 8800 N/mm^2
 - Density = 370 kg/m^3

Timber	Modulus of Elasticity (E) / Young's Modulus N/mm^2
Balsa	3200
Agba	7600
Beech	10,100
Greenheart	21,100
Norway Spruce	10,200
Redwood	10,000
Douglas Fir	12,700

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16. EXAMPLES OF STRUCTURAL USES/TYPES:

- A) **Tongue & Groove Flooring:** 19mm deep will span 600mm.
- B) **Floor Joists:** 44mm wide x 200mm deep joist at 400 centres will span 3.8m with a timber deck above.
- C) **Timber Beams:** 75mm wide x 225mm deep beam will span 2.8m and support 2m of commercial floor load (i.e. a 4m wide room). Max available depth timber is 300 deep.
- D) **Built-up Beams:** glue laminated, plywood box beam and ply web beams are common. A 115mm wide x 560mm deep glue laminated beam will span 10.5m over an exhibition hall at 1m spacing.
- E) **Timber Posts:** A 4 m high post comprising of a 97mm wide x 145 mm deep timber section can carry over 20kN (2 Tonnes).
- F) **Stud Wall:** 44mm x 100mm timber studs at 600mm centres with plasterboard both sides can carry 10kN (1 Tonnes) per metre length.
- G) **Truss:** Made up of struts and ties. A truss rafter tie of 38mm x 100mm and 2.7m long can carry a tension load of 61kN (6 Tonnes)!

